Status and future of the RIA project viz. transactinide elements

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Introduction

The Rare Isotope Accelerator (RIA) is an innovative, large-scale facility that will define the state-of-the-art for the production and use of exotic nuclei. The RIA facility will employ the best features of both projectile-fragmentation (in-flight techniques) and target-fragmentation (ISOL techniques) to provide the widest possible range of exotic nuclei to the nuclear physics community. The project to develop RIA consists of conceptual design as well as research and development studies in many laboratories across the United States. Significant contributions have been made by a very large number of people that, unfortunately, cannot be adequately covered in the present short presentation. In this contribution I will present a brief overview of the RIA facility with an emphasis on the new capabilities for neutron-rich secondary beams.

RIA accelerator

All of the older designs (before the mid-1990's) for the next generation exotic beam facility in the US were based (solely) on the ISOL concept of target fragmentation by light-ion beams (e.g., Nolen [1]). Three important facts emerged during the initial consideration of possible facilities: (A) very sensitive techniques were developed to study nuclear structure with low-intensity fast beams, (B) the limitations from ion-source chemistry on the range of shortest-lived and most exotic nuclei available from ISOL systems were not generally resolved, and most importantly, (C) the IGISOL concept [2], used to thermalize and collection low-energy reaction products, was extended to fast projectile fragments [3,4]. Thus, the scope of the RIA project was increased significantly so that the facility operation would encompass both in-flight and ISOL separation. The optimum production method will be used to produce each secondary beam rather than obtaining those secondary beams available from one or the other technique. This new approach requires the primary or driver accelerator to provide very intense beams of light ions to next-generation ISOL targets as well as intense beams of all heavier stable nuclei to projectile fragment separators. Low energy, target-fragment ions will be extracted from the ISOL targets and accelerated to low energies in the usual way. The high energy, projectile fragments will be delivered to a high-energy experimental arena as well as to a new low energy "ion source" based on new concept of buffer-gas thermalization and reacceleration of projectile fragments. Thus, there will be three different target areas for the primary beam: a set of high power ISOL targets feeding an isobar separator system feeding the low energy accelerator complex, a high intensity projectile fragmentation target with a high resolution fragment separator feeding the high energy complex, and another high intensity projectile fragmentation target with a high acceptance fragment separator connected through a gaseous-ion collector to the low energy complex. The resulting exotic nuclei will be available at four separate experimental regions (ion-source energy, below Coulomb barrier, near Coulomb barrier, and high energy) in order to service a large and diverse user community.

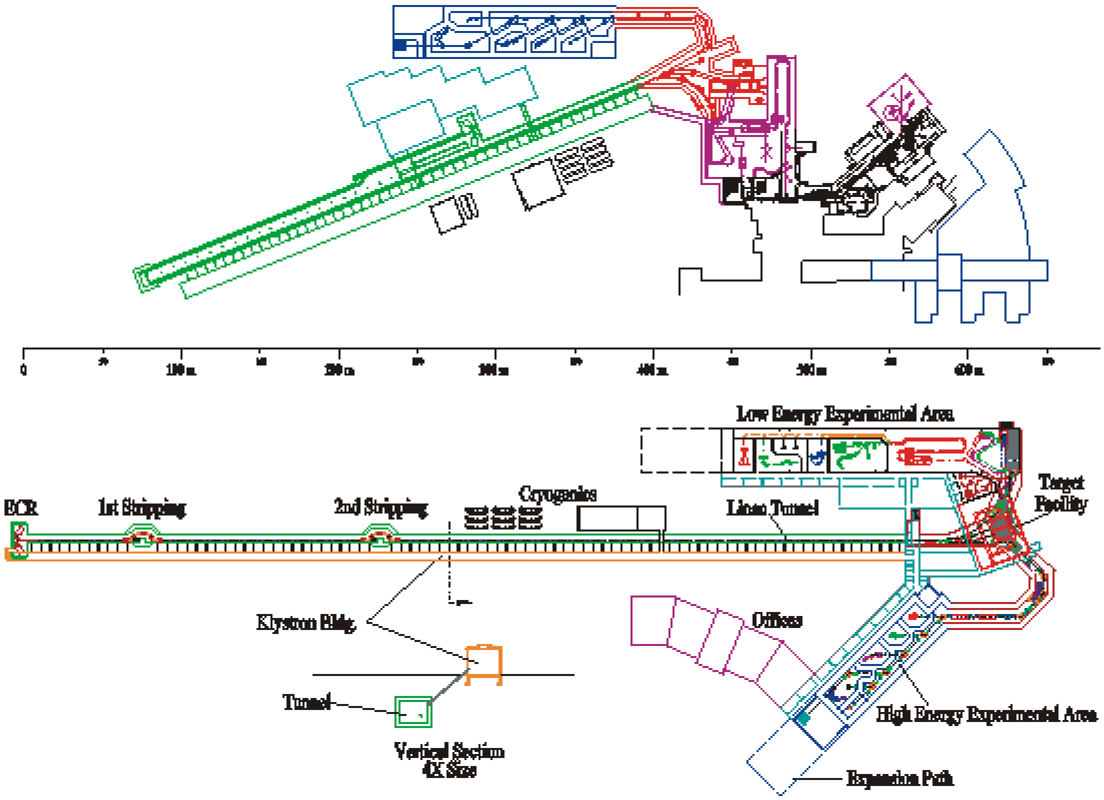

Figure 1. A comparison of the complete RIA facility at the Argonne site (above) and at the Michigan State site (below) at the time of the DoE cost analysis. Both designs contain the same capabilities and experimental areas.

The Nuclear Science Advisory Committee (NSAC) has given RIA the highest priority rating for new construction and has been put forward to the DoE Office of Science as ready for detailed design studies. Preliminary designs for the complete RIA facility have been prepared by the NSCL at Michigan State University and by Argonne National Lab. The schematic layouts of these facilities can be compared in Figure 1. Both layouts are dominated by the layout of the primary linear accelerator that provides beams with E/A ~500 MeV at 400kW up to A~40 and uranium with E/A~400 MeV at 150kW. One difference between the two proposed designs is that the existing ATLAS accelerator is incorporated into the Argonne layout whereas the MSU is a "green field" layout. The technical details of the ion sources, accelerator, target systems, fragment separators, and gas-catchers are being studied in a variety of laboratories around the US. A subcommittee of NSAC has reviewed an independent, bottoms-up cost analysis at the end of 2000. Another DoE panel chaired by Satoshi Otsaki just reviewed the progress on the R&D work in August of this year. An interesting aspect of the RIA accelerator proposed by Ken Shepard and collaborators at Argonne is to have the linac simultaneously accelerate an isotope in multiple charge states to provide very high intensities of the heaviest stable elements. The initial requirements for the experimental facilities and equipment have been prepared by the community [5,6] and have been incorporated into the designs.

Neutron-rich beam production

The neutron-rich beams that will be needed to try new synthetic routes to the heaviest elements will come from either traditional ISOL system or the new ion-collector system. At this point it is too early to tell which technique will be the most useful but the demands of heavy-element research for the highest beam currents favor the ISOL approach. In the well-known ISOL light primary beams such as protons, deuterons, or ^{3}He beams hit thick production targets closely coupled to ion sources. The raw beams from the RIA ion sources are pre-separated and a small number of beams with nearby masses can be simultaneously delivered to a transport network that includes two high-resolution separators. The monoisotopic beams are then transported to either the low-energy experimental area or to the first stage of the post-accelerator. At present ISOL beam production is carried out with primary beam powers on the order of a few tens of kilowatts. The highest-power ISOL facility (20 kW) presently operational is the ISAC facility at TRIUMF in Canada. Concerted and very specific ISOL R&D work has been carried out for many years in Europe at the ISOLDE facility and elsewhere so that a lot of expertise exists in that community. The biggest challenge for ISOL at RIA is to build target systems that can make use of the order of the extremely high beam power. New ideas have been suggested such as converter systems that accept high-energy deuterons to release high-energy neutrons that go on to induce fission. Substantial R&D is required in order to answer key questions about how traditional and new targets can be build and operated in the ½ megawatt domain. Scaling the beam intensities from the present conditions has been used to obtain the yield predictions for the RIA secondary beams.

Fragment separators have developed significantly over the past decade, see for example [7], so that both of the devices planned for RIA will be next-generation superconducting fragment separators that go well beyond the best present day machines. For comparison, the resolving power and a figure of merit for the A1200 (now retired) and A1900 (recently completed) separators at the NSCL can be compared to the specifications of RIA separators in Table 1.

Table 1. Comparison of ion-optical properties of projectile fragment separators based on superconducting magnets. The resolving power is the dispersion divided by the product of the beam spots size and the magnification in the same coordinate (x). The dimensionless "figure of merit" used to categorize the separators is the product of the relative solid angle ($d\Omega/4\pi$), the momentum acceptance ($\Delta p/p$), and the resolving power.

	$\Delta p/p$ (%)	$d\Omega$ (msr)	$B\rho$ (Tm)	Resolving Power	Figure of Merit
NSCL A1200	+/-1.5	0.8	5.4	2400	0.5
NSCL A1900	+/-2.5	8	6	2900	10.2
RIA High Res.	+/-3	10	8	3000	14.3
RIA High Accpt.	+/-9	10	8	1000	14.3

The new approach for the production of thermalized exotic ions for nuclear structure studies has been pioneered at Argonne and at RIKEN based on ion stopping work at GSI [8]. Moderate [4] and fast [3] nuclear reaction products are stopped in large high-purity helium gas cells and extracted as singly-charged ions through the application of drift fields and gas flow. One of the important ingredients of the new concept is the incorporation of an energy-focusing ion-optical device that can compensate for the large momentum distribution of the projectile fragments. Such devices consist of a dispersive magnetic dipole stage and slowing-down of the fragments in specially shaped energy degraders [8]. The feasibility of momentum compensation, also called range bunching, has been recently demonstrated at the GSI-FRS and recently at Michigan State using pressures near one bar [9]. These results and further calculations have shown that the longitudinal range straggling of typical projectile fragments can be brought down to the level of the intrinsic straggling width of an equivalent monoenergetic beam which is, none the less, on the order of one-half meter of helium gas at one bar. The purity of the buffer gas leading to unwanted ion-molecule reactions has large effects on the efficiency of IGISOL systems as has been shown by the

Leuven group [10]. These neutralization and the many possible effects from the ionization plasma in the buffer gas still has to be fully understood for efficient operation of large-scale gas cells. However, it has been reported that the system operating at Argonne has an efficiency of close to 45% and extraction times below 10 milliseconds [4]. Any upper limit on the rate at which ions can be implanted and efficiently extracted from a large gas cell has yet to be experimentally determined. The total production yields from all of the various techniques have been analyzed by Jiang et al. [11] and various tables and figures are available to check the feasibility of experiments at RIA.

One of the interesting aspects of the study of nuclear reactions induced by radioactive beams is the possibility of using n-rich radioactive projectiles to synthesize new, neutron-rich heavy nuclei. It has been shown by Loveland [12] that new areas in the atomic physics and chemistry of the transactinide elements could be developed using intense n-rich radioactive beams. Various authors have suggested that there will be significant enhancements to the fusion cross sections for n-rich projectiles due to the lowering of the fusion barrier, the excitation of the soft dipole mode and the lowering of the reaction Q values for the more n-rich projectiles. The survival probability of the evaporation residues (EVRs) is also expected to increase due to their reduced fissionability and the lowered excitation energy. There is further speculatation that the use of these projectiles might lead to the successful synthesis of new or superheavy nuclei. Takigawa et al., [13] predict an enhancement of 10^5 in the fusion cross section for the $^{46}K + ^{238}U$ reaction compared to the $^{41}K + ^{238}U$ reaction and an increase of a factor of two in the survival probabilities for the EVRs. Experience from the synthesis of new heavy nuclei by non-radioactive n-rich projectiles shows that an increase of one unit in isospin of the projectile increases the heavy element production cross sections by a factor of 5 [14] so that even small changes in the isospin of the compound nucleus are important.

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